Dynamical SUSY Breaking in Meta-Stable Vacua: Part I

Strings, 2006
Beijing

Kenneth Intriligator, Nathan Seiberg and DS
hep-th/0602239

Dynamical SUSY Breaking

Dynamical SUSY Breaking (DSB) is an elegant mechanism for breaking SUSY while preserving naturalness.

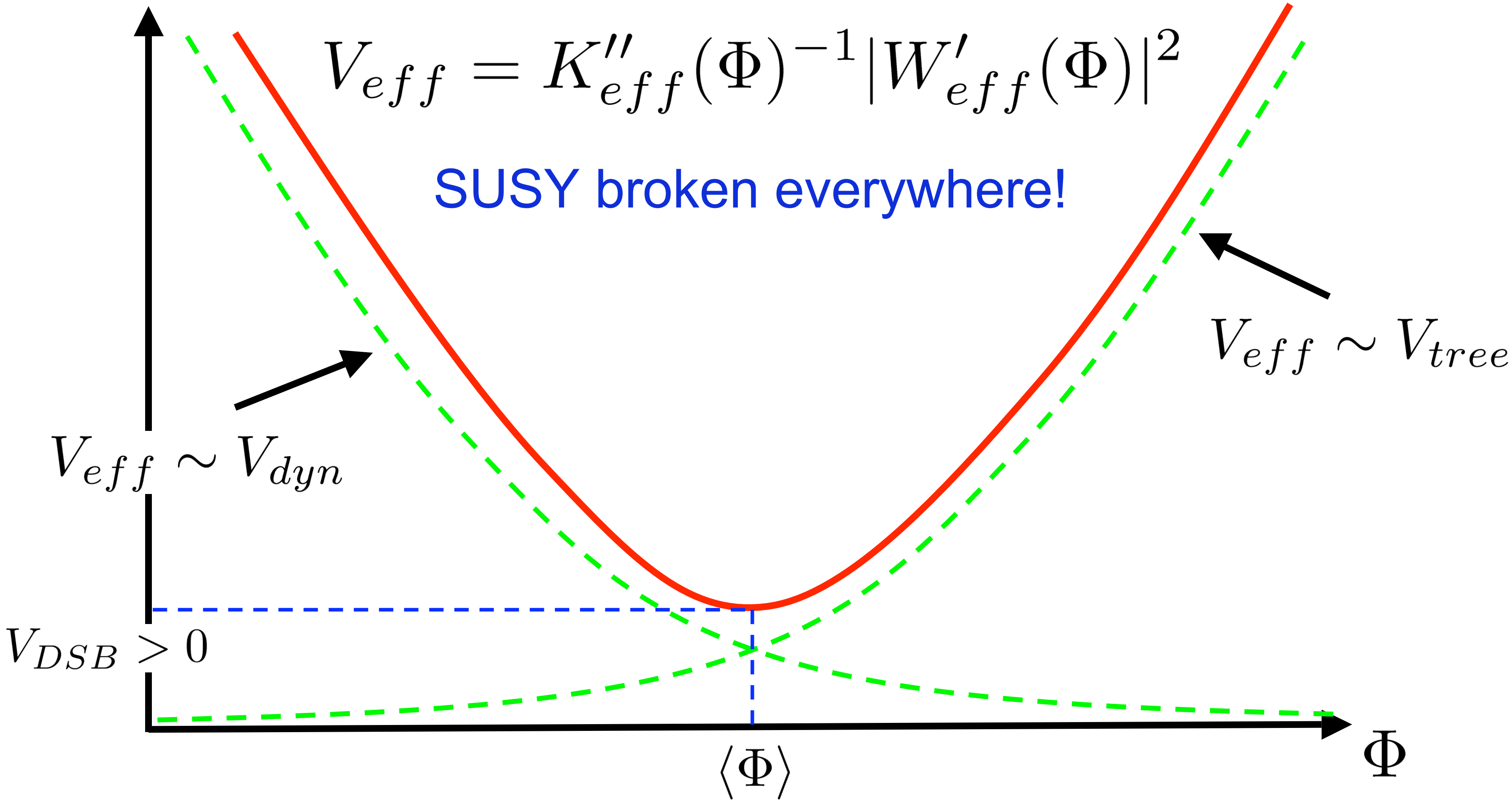
The idea: Nonperturbative effects in a strongly-coupled SUSY gauge theory lead to spontaneous SUSY breaking.

Then SUSY breaking scale and mass splittings are related to some dynamical scale

$$\Lambda = M_{cutoff}\, e^{-\frac{c}{g(M_{cutoff})^2}} \ll M_{cutoff}$$

Can naturally get hierarchies in this way (Witten).

Conventional picture of DSB



Problems with this picture

- DSB is non-generic: many constraints on theories with DSB.

  For example, (almost) all SUSY gauge theories with vector-like matter have $\mathrm{Tr}\,(-1)^F \neq 0$ SUSY vacua. So for completely broken SUSY, need a chiral gauge theory*.

- DSB is hard to analyze: For a detailed analysis of SUSY breaking, quantum corrections must be under control.

  In particular, one needs to know the Kahler potential, which is not protected by holomorphy/chirality/BPS.

*Some vector-like exceptions, with massless matter (Intriligator and Thomas; Izawa and Yanagida).

"Simplest" example of calculable DSB
(Affleck, Dine, Seiberg)

$SU(3) \times SU(2)$ gauge theory with matter:

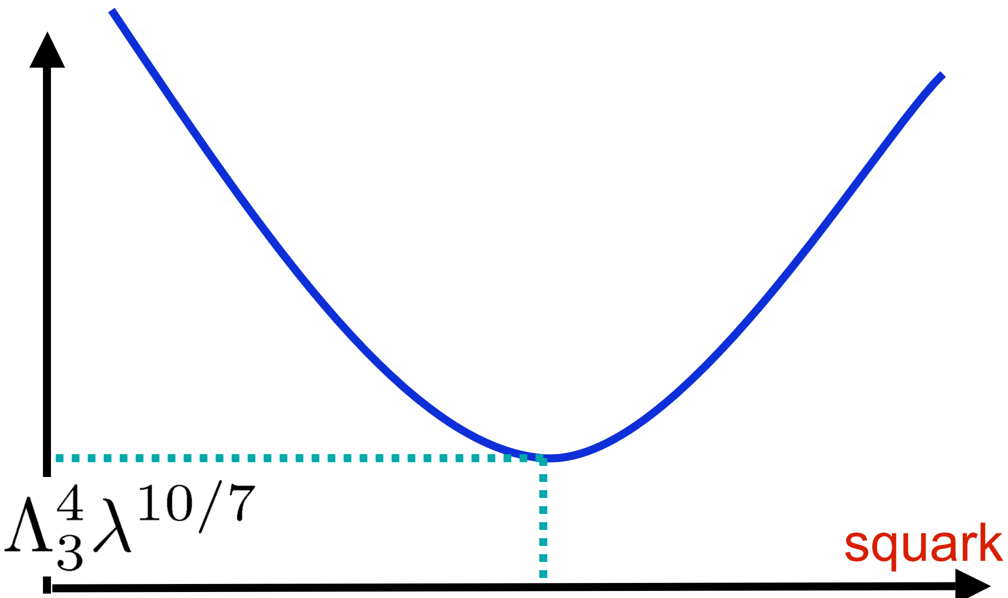
and superpotential

$$W_{tree} = \lambda Q \bar{u}_1 L$$

	$SU(3)$	$SU(2)$	$[U(1)_R]$
Q	$\mathbf{3}$	$\mathbf{2}$	$-\mathbf{1}$
$\bar{u}_{i=1,2}$	$\bar{\mathbf{3}}$	$\mathbf{1}$	$\mathbf{0}$
L	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{3}$

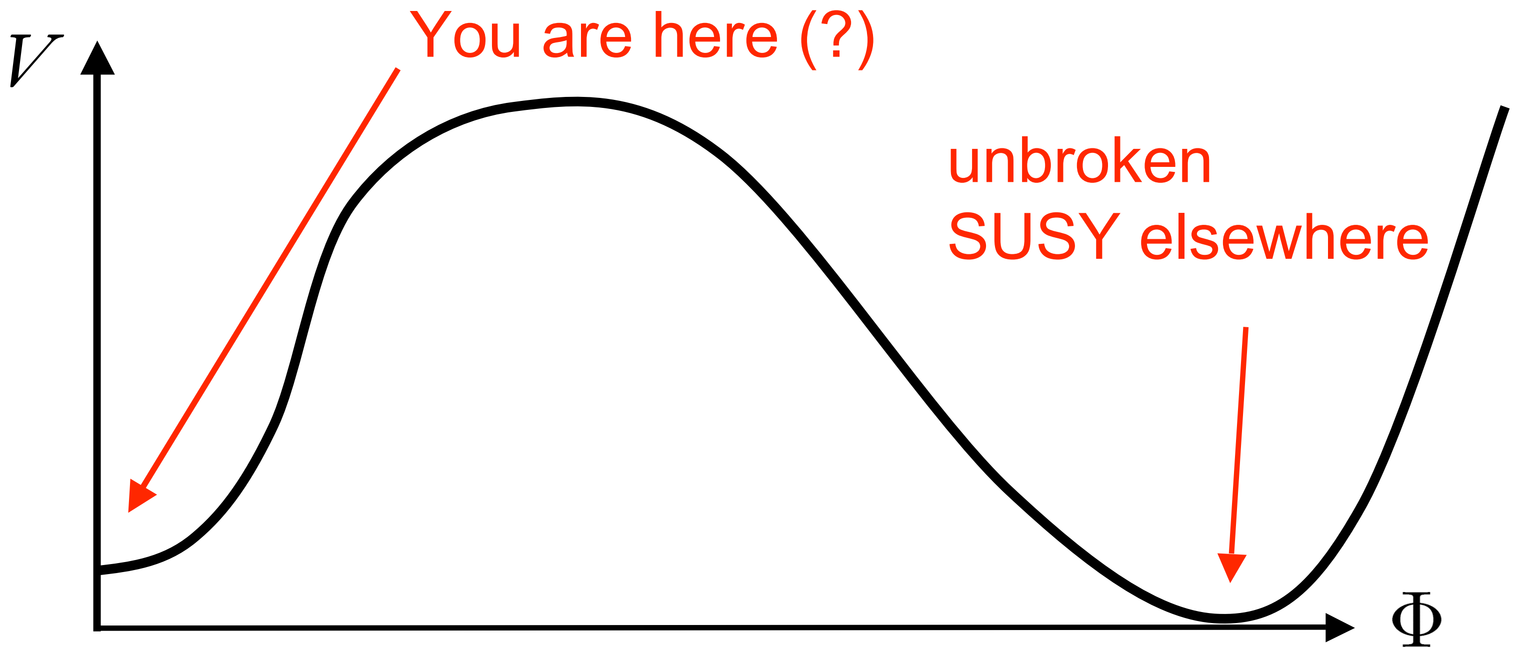
$\lambda \ll 1$ ensures large vevs (weak coupling). Therefore theory is calculable:

$$K_{eff} \approx K_{canonical}$$



Perhaps we should try a new approach...

Maybe the picture is more like this…



Metastable DSB

Metastability is an old idea. However, it has not been used much in model building.

We will find that allowing for metastable vacua can evade many of the classic constraints (e.g. the Witten index).

This leads to much simpler models of DSB.

For example: good old N=1 SQCD!

The Model: Massive N=1 SQCD

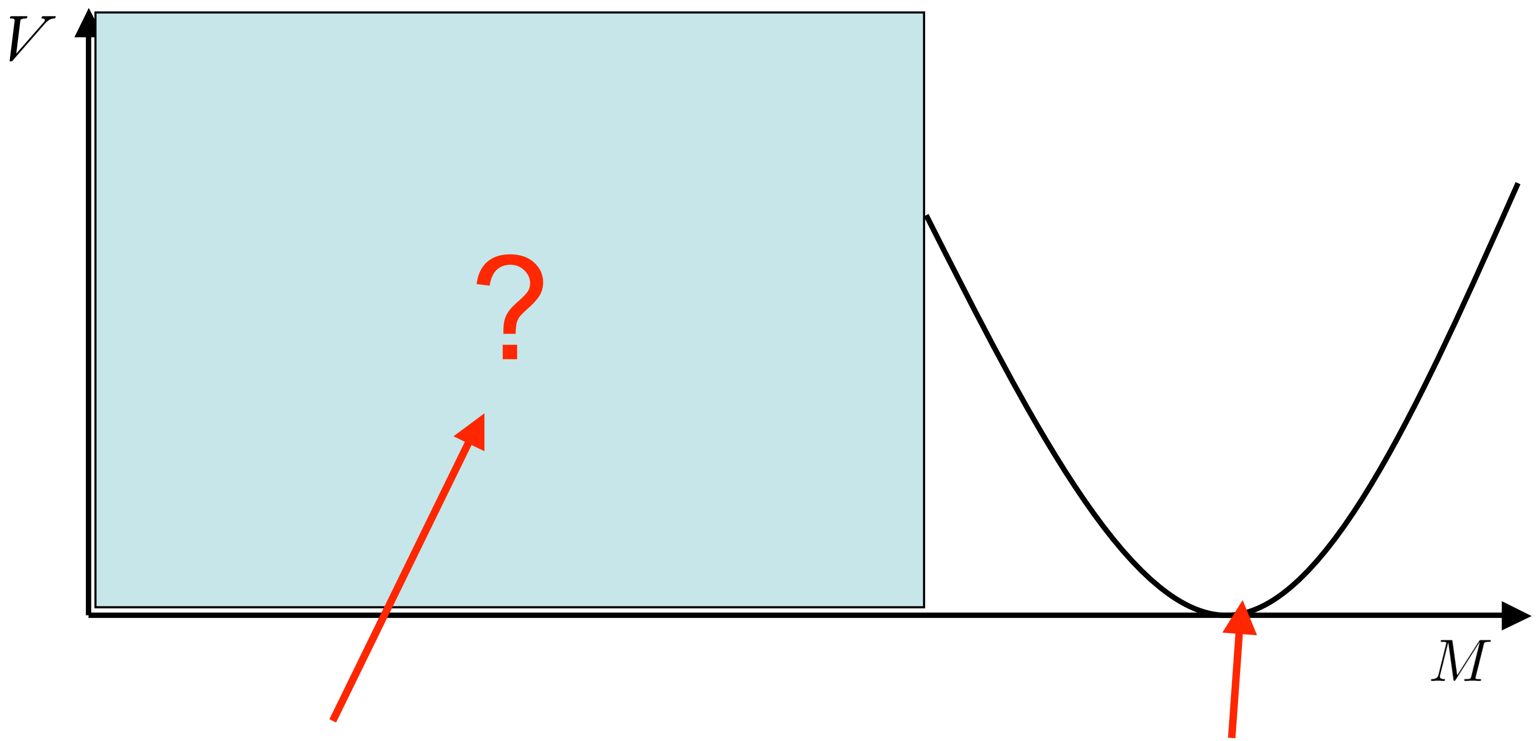
$$
\begin{array}{cccc}
 & SU(N_c) & [SU(N_f) & SU(N_f)] \\
Q & N_c & N_f & 1 \\
\tilde{Q} & \overline{N}_c & 1 & \overline{N}_f \\
(M = Q\tilde{Q} & 1 & N_f & \overline{N}_f\ )
\end{array}
$$

$$W_{tree} = \mathrm{Tr}\, mQ\tilde{Q} = m_0 \mathrm{Tr}\, M$$

This theory is massive and vector-like, so there must be

$\mathrm{Tr}\,(-1)^F = N_c$ SUSY vacua

A sketch of the potential



Potential near the origin can be uncovered using Seiberg duality

N_c SUSY vacua

$$\langle M \rangle \sim \left(\Lambda^{3N_c - N_f} m_0^{N_f - N_c} \right)^{1/N_c}$$

Review of Seiberg Duality

Electric: $W_{tree} = m_0 \mathrm{Tr}\, Q\tilde{Q}$

	$SU(N_c)$	$[SU(N_f)$	$SU(N_f)]$
Q	N_c	N_f	1
$\tilde{Q}$	$\overline{N}_c$	1	$\overline{N}_f$

Magnetic. $W_{dual} = \frac{1}{\Lambda} \mathrm{Tr}\, qM\tilde{q} + m_0 \mathrm{Tr}\, M$

	$SU(N_f - N_c)$	$[SU(N_f)$	$SU(N_f)]$
q	$N_f - N_c$	N_f	1
$\tilde{q}$	$\overline{N_f - N_c}$	1	$\overline{N}_f$
M	1	$\overline{N}_f$	N_f

Classically different. Quantum theories the same in the IR.

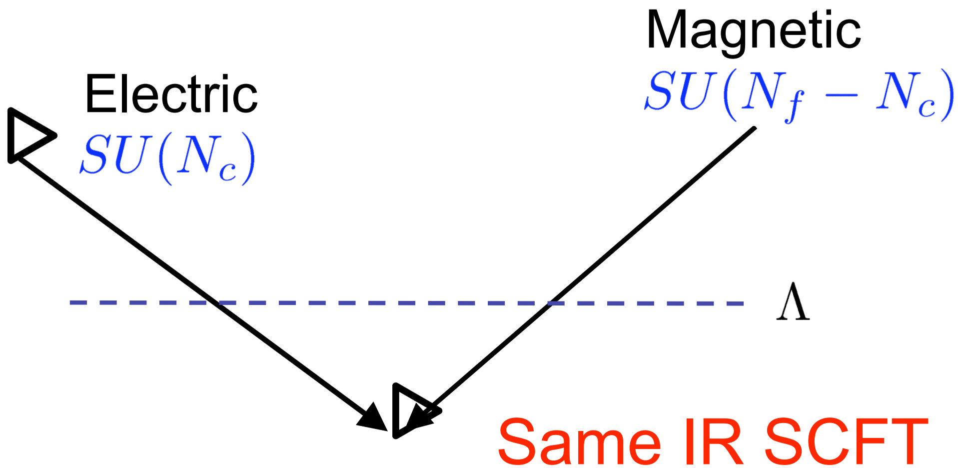
Seiberg Duality, part II

Beta functions: $\beta_e = 3N_c - N_f, \quad \beta_m = 2N_f - 3N_c$

$$\frac{3}{2}N_c < N_f < 3N_c$$

"Conformal window"

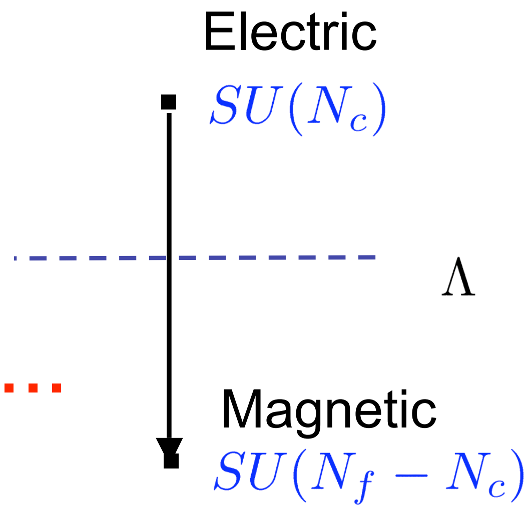
Interacting superconformal field theory.



$$N_c < N_f \leq \frac{3}{2}N_c$$

"Free magnetic phase"

Magnetic theory is IR free ...



Focus on the free-magnetic phase

Let's focus now on $N_c < N_f \leq \frac{3}{2}N_c$ where theory is IR free.
Then the Kahler potential is smooth near the origin:

$$K = \frac{1}{\alpha\Lambda^2}\mathrm{Tr}\, M^\dagger M + \frac{1}{\beta}\mathrm{Tr}(q^\dagger q + \tilde{q}^\dagger \tilde{q}) + \ldots$$

Key point: the leading Kahler potential is known, up to two dimensionless normalization constants.

Using this, we can compute the scalar potential near the origin.

"Rank condition" SUSY breaking

$$W_{dual} = \frac{1}{\Lambda} \mathrm{Tr}\, q M \tilde{q} + m_0 \mathrm{Tr}\, M$$

$$V_{tree} = \frac{1}{\Lambda^2} \beta \left(|M\tilde{q}|^2 + |Mq|^2 \right) + \alpha |\tilde{q}q + m_0 \Lambda|^2$$

SUSY is broken at tree-level:

$$V_{tree} \supset \alpha \sum_{fg} |\tilde{q}_{fc} q^c_g + m_0 \Lambda \delta_{fg}|^2 \neq 0$$

(rank N_f -N_c) (rank N_f)

(Of course, this SUSY breaking is a check of the duality.
Otherwise, we would have had extra SUSY vacua.)

Non-SUSY vacua of the magnetic theory

$$V_{tree} = \frac{1}{\Lambda^2}\beta\left(|M\tilde{q}|^2 + |Mq|^2\right) + \alpha|\tilde{q}q + m_0\Lambda|^2$$

Classical vacua (up to global symmetries):

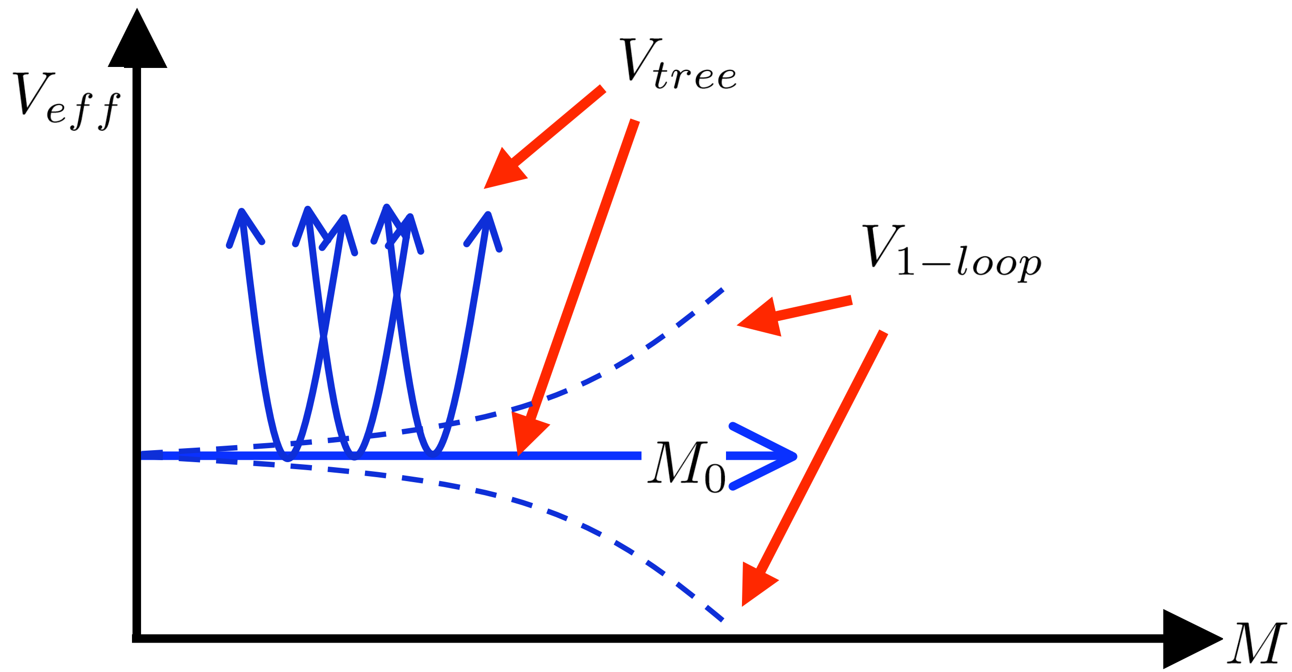
$$M = \begin{pmatrix} 0 & 0 \\ 0 & M_0 \end{pmatrix}, \quad q = \begin{pmatrix} q_0 \\ 0 \end{pmatrix}, \quad \tilde{q} = \begin{pmatrix} \tilde{q}_0 \\ 0 \end{pmatrix}, \quad q_0\tilde{q}_0 = -m_0\Lambda$$

Arbitrary $N_c \times N_c$ matrix $\quad (N_f - N_c) \times (N_f - N_c)$ matrices

$$V_{min} = N_c\alpha\,|m_0\Lambda|^2 \neq 0$$

Potential for the pseudo-moduli

M_0 and $(q_0, \tilde{q}_0)$ parameterize a pseudo-moduli space.



This space is lifted in perturbation theory, since SUSY is broken.

Potential for the pseudo-moduli, cont'd

1-loop effective potential for pseudo-moduli:

$$V_{1-loop} = \frac{1}{64\pi^2} \mathrm{Tr}\,(-1)^F \mathcal{M}^4 \log \frac{\mathcal{M}^2}{\Lambda^2}$$

1-loop vacuum energy

mass matrices, as a function of the pseudo-moduli.

Claim: the 1-loop effective potential is minimized at the point of maximal unbroken global symmetry:

$$M = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}, \qquad q = \tilde{q} = \begin{pmatrix} \sqrt{-m_0 \Lambda}\, \mathbf{1}_{N_f - N_c} \\ 0 \end{pmatrix}$$

Stabilizing the non-SUSY vacua

Proof: compute the effective potential at a nearby point along the pseudo-moduli space

$$M = \begin{pmatrix} 0 & 0 \\ 0 & \delta M \end{pmatrix}$$

$$q = \begin{pmatrix} \sqrt{-m_0\Lambda} + \delta q \\ 0 \end{pmatrix}, \quad \tilde{q} = \begin{pmatrix} \sqrt{-m_0\Lambda} - \delta q \\ 0 \end{pmatrix}$$

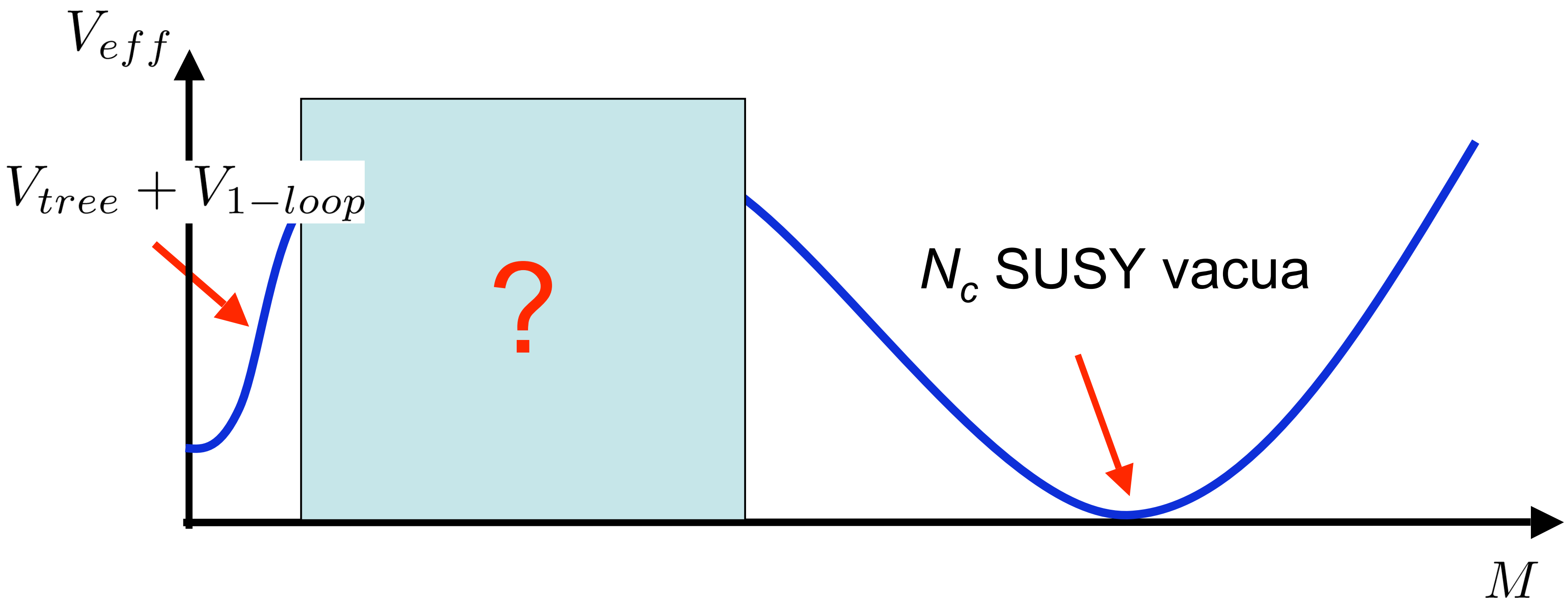
The result is…

$$V_{1-loop} \sim |m_0\Lambda| \mathrm{Tr}\left[(N_f - N_c)\delta M^\dagger \delta M + N_c(\delta q + \delta q^\dagger)^2\right]$$

The mass-squareds are all positive!

Meta-stable DSB

Thus we have found a meta-stable SUSY-breaking vacuum in SUSY QCD! **(Almost…)**



(Vacuum is mysterious in electric description: not semi-classical, very quantum mechanical.)

Summary of Part I

- Motivated by the search for simpler models of DSB, we looked for SUSY gauge theories with metastable vacua.

- We found a surprisingly simple model with metastable vacua: massive N=1 SQCD.

- Our results suggest that metastable vacua are common in N=1 SUSY theories and in string theory.

Preview of Part II

- Controlling other corrections to the scalar potential
- The SUSY vacua in the magnetic dual
- Lifetime of the metastable vacuum
- Possible applications to phenomenology, cosmology